Seaweb Network for FRONT Oceanographic Sensors

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LONG-TERM GOAL

Our goal is to accomplish near-real-time data telemetry for a set of widely spaced oceanographic sensors by using undersea acoustic signaling (telesonar) and specialized networking (seaweb).

OBJECTIVE

The Front-Resolving Observational Network with Telemetry (FRONT) is a study supported by the National Oceanographic Partnership Program (NOPP) and led by the University of Connecticut (Groton, CT). Spatial sampling of ocean frontal features on the inner continental shelf requires sensor distribution over roughly a 10-km by 10-km measurement area. Sensors sparsely deployed on the bottom in 20- to 60-m water, as charted in Figure 1, need sensor-to-shore data delivery and shore-to-sensor remote control.

Figure 1. The FRONT site lies outside Block Island Sound in 20- to 60-m continental shelf water. It is a complex environment influenced by strong tidal currents, buoyant estuarine outflow, seasonal variations, and poorly understood subtidal fluctuations driven by wind and offshore circulation. The original concept for FRONT node placement involved 8 sensor nodes at the white symbols and 2 gateway nodes at Coast Guard navigation buoys designated with black symbols. The observatory concept has evolved as our NOPP science partners have learned about the spatial variability of the environment and as project engineers have learned about the limitations of telesonar transmission in these waters.

This project advances communications technology enabling synoptic observation of the FRONT undersea environment. Vulnerability of seafloor cables to commercial trawling precludes the use

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of a wired network. Vulnerability of sea-surface buoys to weather, shipping, and pilfering discourages reliance on radio telemetry from individual sensor nodes. We explore the formation of a wireless sensor grid by applying seaweb technology now being developed for distributed undersea surveillance and other Naval missions. The oceanographic conditions making the FRONT site so interesting also pose a challenge for seaweb because of the inherent reliance on this complex ocean environment as our communications medium. We expect the very data seaweb delivers to our NOPP partners will help us understand any variable quality of service experienced by the network under stressful channel conditions.

APPROACH

Seaweb supports packeted telemetry, remote control and interrogation of undersea instruments. We are working toward a long-range goal of networking dissimilar, arbitrarily placed, asynchronous, stationary and mobile nodes using auto-configuration, self-optimization, self-healing, and environmental adaptation. We are presently advancing seaweb technology to support fleet demonstrations of a littoral ASW future Naval capability known as the Deployable Autonomous Distributed System (DADS). DADS sensor topologies, information throughput, and battery constraints are similar to those of FRONT. Hence FRONT requirements are well matched to the present telesonar state-of-the-art. Gateway technologies, internet links, and our seaweb server command-center interface have direct application to FRONT.

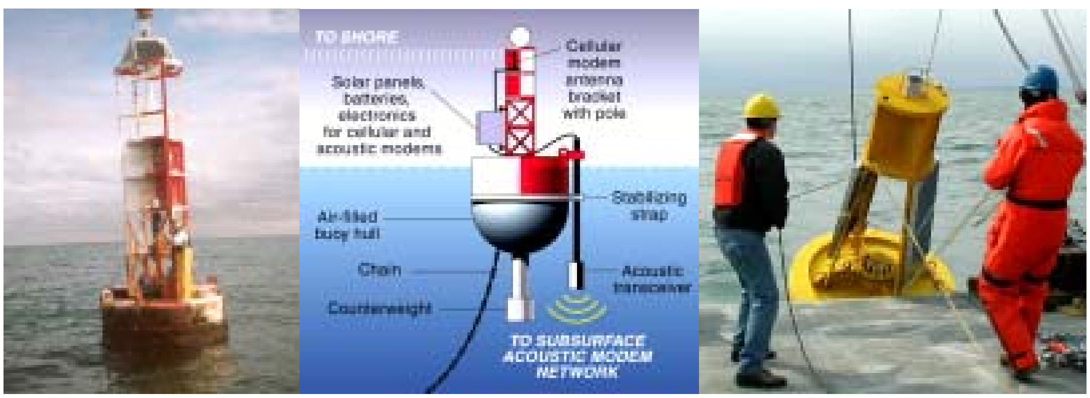

Figure 2. Left: Coast Guard buoys serve as radio-acoustic communications (racom) gateway nodes at two fixed locations. Center: A cellular digital packet data (CDPD) modem communicates via the terrestrial wireless telephone grid to the internet and thence to the ashore seaweb server and FRONT client software routines. A submerged telesonar modem transducer communicates with undersea seaweb nodes. Right: A University of Connecticut buoy is a deployable racom gateway node affording flexibility of placement in the network.

Although Seaweb 2001 firmware can now accommodate packets up to 2 kilobytes, we are working with our NOPP partners to compress data packet content to about 350 bytes for battery-energy efficiency and improved performance. For the 1999-2002 FRONT study, telesonar modems operate in the 9- to 14-kHz acoustic band and employ M-ary Frequency Shift Keying (MFSK), a multipath-resistant modulation method. Hadamard coding and convolutional coding provide resistance to other channel impairments such as frequency-selective fading and non-white ambient noise. The net transmission rate of this inherently channel-tolerant signaling is

300 bit/s. Experience gained at the FRONT site is contributing to the development of adaptive telesonar modems that probe the channel, estimate the prevailing propagation characteristics, and then adjust the signaling parameters for increased energy efficiency and channel capacity.

We are measuring and analyzing the site for acoustic propagation and environmental constraints on telesonar transmission. Repeater nodes in our FRONT networks increase area coverage, improve communication links, and relay packets to near-shore gateway nodes. Judicious deployment design yields multiple redundant routes between sensor nodes and gateway nodes, permitting the shore-based network administrator to remotely reconfigure the network. Thus, we can optimize network performance and endure a limited number of node failures. Likewise, we can readily assimilate new node additions. The FRONT application lets us relate developmental seaweb performance to a demanding time-variant ocean environment well characterized by our NOPP science partners and by our numerical telesonar channel model.

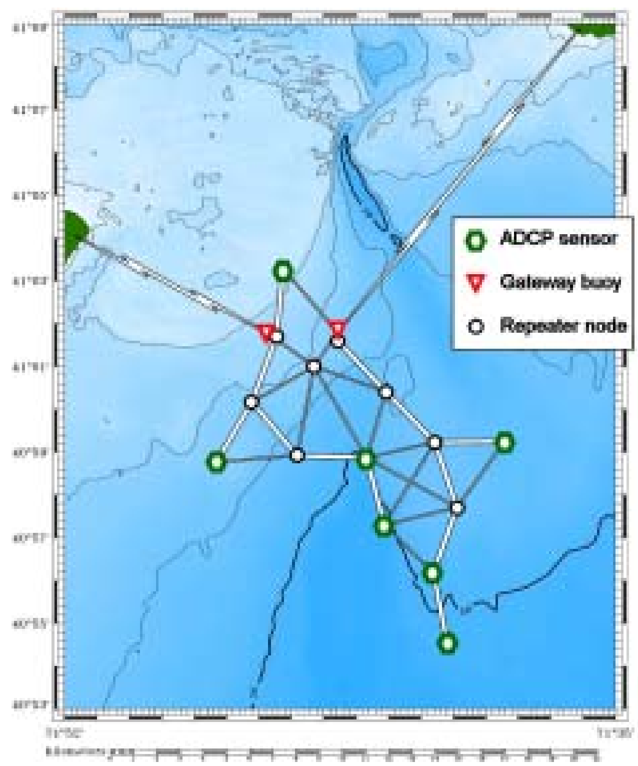

Figure 3. The FRONT-3 seaweb network includes 2 sea-surface racom gateway nodes, 7 seafloor ADCP sensor nodes and 8 seafloor repeater nodes. The repeater nodes reduce node spacing and improve overall quality of service. 2 of the repeaters are adjacent the racom buoys to ensure reliable links between the seafloor grid and the sea-surface gateways. Binary-tree routing topologies as shown with bold white segments minimize multi-access channel contention for half-duplex telesonar links. Routes are configurable by the ashore network administrator using the seaweb server. Although statistics are not yet compiled for FRONT-3 network performance, the 17-day ForeFRONT-3 engineering network delivered 85% of the ADCP data packets to shore with 0 bit-errors.

WORK COMPLETED

Ocean experiments performed in association with our NOPP partners include:

Experiment	Dates	Sensors	Gateways	Repeaters	Total nodes
Seaweb '99	Aug-Sept, 1999	3	2	10	15
ForeFRONT-1	Oct, 1999	1	1	1	3
FRONT-1	Dec, 1999	2	1	4	7
ForeFRONT-2	April, 2000	2	1	5	8
FRONT-2	June, 2000	2	1	5	8
Seaweb 2000	Aug-Sept, 2000	4	3	10	17
ForeFRONT-3	Oct-Nov, 2000	1	1	5	7
FRONT-3	March-May, 2001	7	2	8	17
Seaweb 2001	Aug-Sept, 2001	2	2	8	12
ForeFRONT-4	Oct-Dec, 2001	2	2	2	6
FRONT-4	Jan-June, 2002	8	2	4	14

The annual Seaweb experiments are prolonged, intensive engineering activities largely funded by our other US Navy seaweb projects, and they serve to substantially advance telesonar and seaweb technology. We perform the ForeFRONT experiments at the FRONT site for mitigating risks and learning about the seasonal propagation environment. The FRONT experiments are longer duration deployments with near-real-time oceanographic data collection.

Figure 2 shows a Coast Guard buoy and a deployable buoy instrumented as a radio-acoustic communications (racom) gateway with a 3-m deep telesonar transducer and a cellular digital packet data (CDPD) modem. Through these gateway nodes, the FRONT networks are linked to the internet and are monitored by the US Navy seaweb server. FRONT networking involves multiple sensor nodes, repeater nodes, and gateway nodes, as illustrated by the FRONT-3 network in Figure 3. All network nodes include a battery-powered telesonar modem supplied by Benthos, Inc. (N. Falmouth, MA) with US Navy seaweb firmware operating on the digital signal processor (DSP) chip. Figure 4 shows the FRONT-3 telesonar modems during pre-deployment lab testing at the University of Connecticut. For the sensor nodes, we interface a telesonar modem with the particular FRONT oceanographic instrument, such as an autonomous conductivity-temperature-depth (CTD) vertical profiler supplied by Ocean Sensors, Inc. (San Diego, CA). Figure 5 depicts a sensor node based on an acoustic Doppler current profiler (ADCP) supplied by RD Instruments, Inc. (San Diego, CA).

RESULTS

FRONT is proving the viability of delivering asynchronous digital data from various commercial oceanographic sensors via multiple battery-powered telesonar nodes. Seaweb 2000 and subsequent experiments employed the new ATM885 telesonar modem specifically built for networked applications such as FRONT. The CDPD racom gateway developed for FRONT has proven to be a versatile means for remote TCP/IP access to seaweb networks in near-shore areas having cellular telephone coverage. In Seaweb '99 and subsequent experiments, we remotely reconfigured the network routing topology, performed networked node-to-node ranging, exercised routine node-to-node data packet transfer, and controlled sensor characteristics for adaptive sampling.

Figure 4. Immediately preceding FRONT-3 deployment, project personnel programmed and exercised the seaweb network and the seaweb server as an in-air acoustic network for 2 weeks.

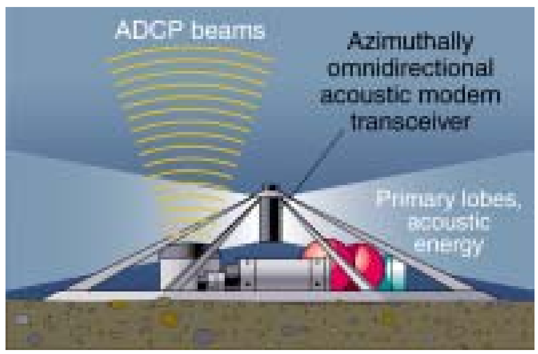

Figure 5. The ADCP sensor nodes are housed in seafloor frames designed and built by University of Connecticut to have a low-profile pyramidal shape intended to deflect trawling gear. The telesonar modem 4-element vertical-line-array transducer resides in the apex of the frame and has a beampattern for azimuthally omnidirectional transmission and reception. All other components lie below the main lobe of the telesonar beampattern.

Fall and winter conditions at the FRONT site are characterized by high ambient noise and upward refracting sound propagation. These conditions scatter sound energy at the sea surface and reduce signal-to-noise ratios (SNR), thus limiting communications range. Telesonar performance over an 8-day period during which high winds correlate with impaired quality of service is shown in Figure 6.

Spring and summer environments exhibit extreme spatial and temporal variability in sound-speed profiles caused by the confluence of various water masses. Downward refraction prevalent during warm seasons favors communication between seafloor nodes. Communications were achieved at ranges up to 10 km, a surprisingly good result, especially in the absence of refractive ducting. Listening modems at various ranges logged SNR, automatic gain control (AGC), cyclic redundancy checks (CRC), bit-error rates (BER), and decoded data packets.

FRONT-1, FRONT-2 and FRONT-3 emphasized reliable data delivery through handshaking and automatic repeat requests. These experiments also evolved the seaweb server for shoreside network management, and produced FRONT client software for sensor-specific control. FRONT-4, charted in Figure 7, will be the longest duration deployment, and will automatically collect network diagnostics to aid seaweb performance analysis. FRONT-4 introduces our use of the MySQL database as a world-wide-web graphical user interface to the near-real-time data stream for the scientific community.

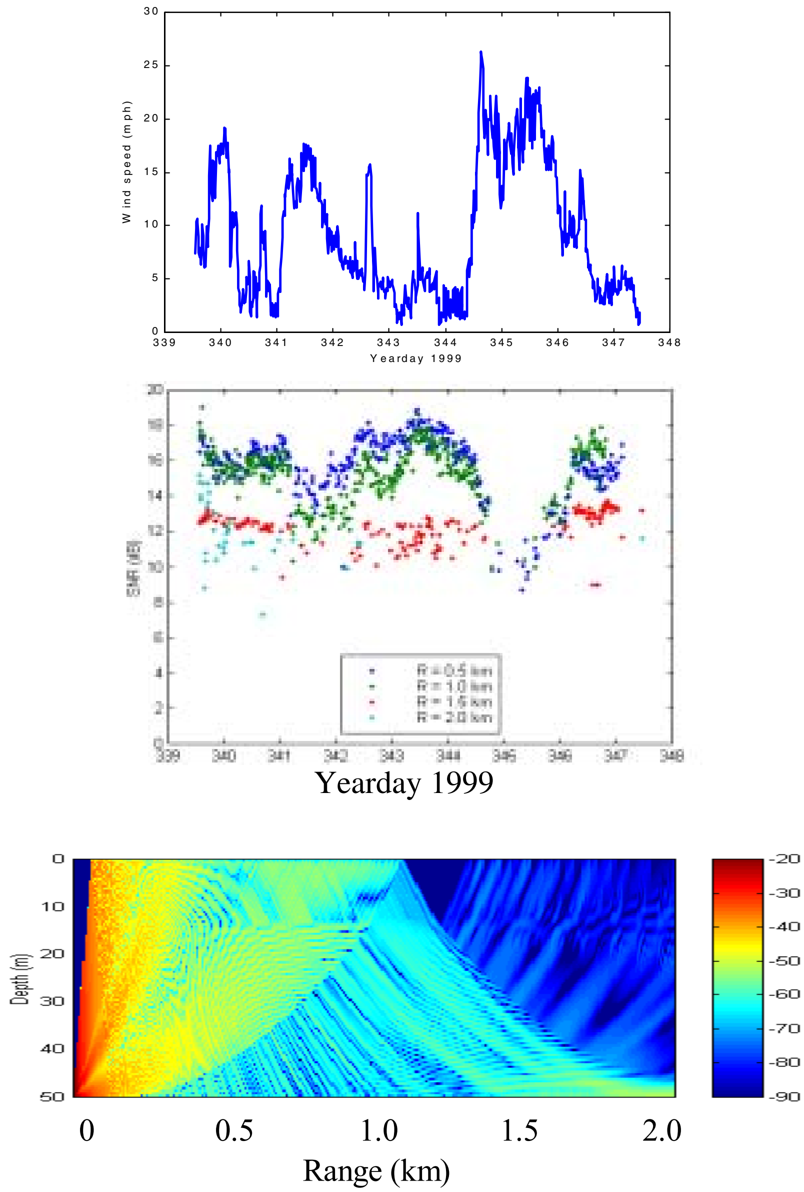

Figure 6. Top: Wind speed (knots) during the 8-day FRONT-1 deployment. Middle: Measured acoustic modem signal-to-noise ratio (SNR) for transmissions between nodes on seafloor at ranges 0.5, 1.0, 1.5, and 2.0 km (blue, green, red, and teal, respectively). Low SNR and communication outages correlate with strong winds. Bottom: Sound intensity (dB scale) from a seafloor source as a function of range and water depth. Direct environmental measurements and numerical propagation modeling indicate this winter ocean water is upward refracting, supporting the hypothesis that reflection losses at the wind-roughened sea surface and elevated ambient noise from the sea surface both decrease SNR.

With the objective of self-configuring, scaleable networks for undersea warfare applications, we are performing basic research in acoustic propagation and coordinating the development of signaling theory, handshake protocols, modems, directional transducers, gateway concepts, and multi-user access strategies. The FRONT installations permit prolonged observation of the relationship between network performance and independently observed environmental influences.

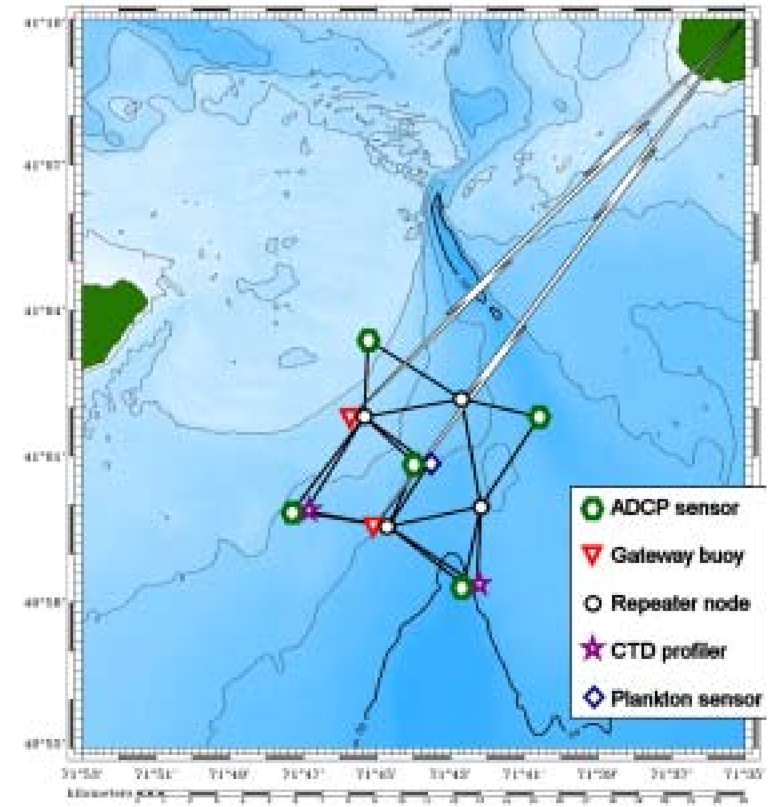

Figure 7. Plans for the FRONT-4 seaweb network call for 2 CDPD gateway nodes, 5 ADCP nodes, 1 autonomous vertically profiling plankton observatory (AVPPO), 2 autonomous CTD vertical profilers, and at least 4 repeater nodes. The FRONT-4 network will use Seaweb 2001 firmware and will operate for up to 6 months. ForeFRONT-4 will test a subset of the FRONT-4 network for risk mitigation.

IMPACT / APPLICATIONS

FRONT furthers the concept of extending into the undersea battlespace a network-centric architecture for overarching command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR). Seaweb provides great flexibility for rapidly deploying and reconfiguring distributed, unattended resources in a given ocean environment, as would be required for a Naval expeditionary sensor grid (ESG). FRONT demonstrates the application of seaweb networks for synoptic measurement of meteorologic and oceanographic (METOC) phenomena using mixed sensor types. An important defense application of FRONT networking is the autonomous monitoring of our

bays, estuaries, rivers, reservoirs and other homeland waterways against the threat of biological, chemical, and radiological contamination.

TRANSITIONS

FRONT is a non-military application of seaweb, offering us the opportunity to accelerate technology development for numerous critical Navy applications such as littoral ASW and autonomous operations. FRONT involves an operating environment, node spacing, and data rates similar to those of DADS and other undersea warfare applications. During the June 2001 Fleet Battle Experiment India (FBE-I), many of the seaweb refinements implemented for FRONT were dramatically demonstrated in conjunction with two prototype DADS sensors networked with an ashore ASW command center and a submerged US Navy fast-attack submarine.

RELATED PROJECTS

This project is one of several FRONT activities funded by NOPP. FRONT is coordinated by the University of Connecticut, Department of Marine Sciences. Other FRONT partners are Massachussetts Institute of Technology, Woods Hole Oceanographic Institution, University of Rhode Island, Naval Undersea Warfare Center, Benthos, Inc., and CODAR, Inc.

This project is also performed as a component of the US Navy Seaweb Initiative. SPAWAR Systems Center, San Diego established the Seaweb Initiative for advancing a C4ISR infrastructure linking diverse undersea assets and including gateways to manned command centers submerged, afloat, aloft, and ashore. The Seaweb Initiative involves the following telesonar research & development efforts:

- SSC San Diego ILIR Telesonar Channels Project (6.1)
- ONR 321SS Telesonar Technology Project (6.2)
- ONR 322OM Signalex Project (6.2)
- ONR 321SI DADS Field-Level Data Fusion Project (6.2)
- ONR 321SS Deployable Autonomous Undersea Systems Project (6.2)
- ONR 321SS Telesonar Technology for Off-board and Deployable Systems Project (6.2)
- ONR 321SI DADS Demonstration Project (6.3)
- NWDC FBE-India Sublink Project (6.3)
- ONR 36 SBIR topic N93-170 (telesonar modems)
- ONR 36 SBIR topic N97-106 (telesonar networks)
- ONR 36 SBIR topic N99-011 (telesonar directional transducers)

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This project is affiliated with work summarized in the following ONR FY01 reports:

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- J. A. Rice, "Telesonar Technology for Off-board and Deployable Systems"
- T. N. Roy, "Deployable Autonomous Distributed System Demonstration"
- J. M. Stevenson, "Deployable Autonomous Undersea Systems"
- V. K. McDonald and M. B. Porter, "Signalex: Relating the Channel to Modem Performance"

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